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TORNADOES.

SECOND PRIZE ESSAY.

BY

Alexander (George)
A. McADIE.

1890

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TORNADOES.

SECOND PRIZE ESSAY.

BY

A. McADIE, M.A. (Harvard)

FELLOW AT CLARK UNIVERSITY.

The Chief Signal Officer in the annual report for 1887,* takes this very conservative position, the practicability of predicting tornadoes. "The Chief Signal Officer feels that neither the "present condition of the science of meteorology, nor the prac- "tical needs of the country, would justify such forecasts. So "almost infinitesimal is the area covered by the line of tornado "in comparison with the area of the state in which it occurs, "that even could the Indications Officer say with absolute cer- "tainty that a tornado would occur in any particular state or "even county, it is believed that the harm done by such a pre- "diction, would eventually be greater than that which results "from the tornado itself. The Service goes as far as is deemed "proper in predicting from time to time *that conditions are* "*favorable for severe local storms.*" †

Before proceeding to the discussion of our knowledge of the tornado, which of right should precede any argument as to the propriety and necessity of prediction, we may, none the less, be allowed to question the reasoning of the paragraph quoted. ‡

* Page 22.

† Italics mine.

‡ The writer expressly disclaims any intention of criticism of the Signal Service, and here and elsewhere merely asserts his right to differ from published opinions.

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If the acquisition of knowledge is one of the prime aims of existence, we must not defer its pursuit because of a fear of the consequences ensuing, due to ignorance! Nor can the commotion and alarm of a community, fearful of misdirected prediction, be fairly weighed against the benefits and advantages to a community warned of the likelihood of a tornado, in that section or county, within a given time! And, yet further, has the Indications Officer the right to cloak under the term, "severe local storms" * the possibility of a "tornado," leaving the section for which the prediction was made, to these very terrors of imagination, hinted at, as valid reasons for not giving a concise and definite statement of the danger likely to occur! The forces brought into action in "severe local storms" may be met and opposed — successfully — as far as the elements of destructiveness to life and property is concerned; but the forces developed in the progress of the tornado, are not comparable with those we would offer in opposition. An example will illustrate the difference. What will be the force of the wind upon the wall of an ordinary dwelling house, say 25 feet high and 40 feet long? The pressure of the wind is as the square of the velocity, and also as the density of the air. The formula†

$$p = \frac{s^2}{151.7\,(1+.004\,T)} \cdot \frac{P}{P_0} S$$

gives us p, the pressure in grams; s, the velocity of the air; P, the observed barometric pressure; P_0 the standard pressure; S, the area of surface exposed, in square centimeters; $(1+.004\,T)$ co-efficient of expansion of air in ordinary hygrometric condition; and which multiplied by the factor 151.7 and $\frac{P}{P_0}$ — approximately represents the density of the air. From this we shall find that the pressure in grams per square centimeter upon our wall, if normal to the direction of the wind, would be, for a wind of fifty miles per hour velocity, approximately 3 grams per square centimeter; and as our wall is 1000 square feet or approximately 925,000 square centimeters we should have a total pressure exerted upon the wall of about 2,775,000 grams or 2,775 kilograms, which we may call roughly a pressure of over 5 pounds to the square foot, or a total pressure

* Ferrel (20) page 302.
† Ferrel (20) page 302.

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of something like 5,000 pounds. For wind velocities of about 100 miles per hour, the pressure would not be simply doubled to about 10 pounds per square foot, but more nearly three times this, or about 30 pounds. If we take a velocity of 300 miles per hour—and this does not seem an extravagant estimate;—(according to Finley, the vortex wind velocities of tornado cloud vary from 100 to 500 miles per hour—as deduced from actual measurement*)—we have a pressure of approximately 120 grams per square centimetre, or nearly 250 pounds per square foot, or a total pressure on the supposed wall of 250,000 pounds. In other words, concerning the force components that have a destructive effect on standing walls, buildings, etc., if we represent the efficiency of those developed in a "*severe local storm*," by 1, we should represent those developed by a tornado, by 50, *at least*, for in our estimate, we have considered only effects due to the enormous increase of wind-velocity, and undoubtedly there are other factors, destructive in their operation.

For this and other reasons, we think, that the terms, "*local storm*" "*tornado*," (and "*cyclone*,") should be used with discrimination, especially at this time, when the tendency is so marked to use all storm-type names, synonymously.

We propose in this paper to discuss, 1st, *the nature and general characteristics of a tornado;* 2d, *the possibility and practicability of predicting tornadoes.*

Under the first head, we may call all motions of the atmosphere due to a condition of unstable equilibrium of the atmosphere, and in which the initial motion is due to a difference in temperature, *cyclones.*

Different types of storm embraced under the generic term cyclones, are

A. Proper cyclones, or large cyclonic movements of the atmosphere as distinguished from the general circulation;

B. Sub-cyclonic storms; the tornado, water-spout, hail-storm and thunder-squall.

The points of difference and resemblance between these classes may be summed up as follows:

Cyclone proper differs from tornado,

a. In extent;

b. The increase of temperature in certain parts, arises less from the energy of the storm itself, than from extraneous

*Reference given further on.

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causes; *i. e.* although much heat may be evolved by the process of condensation and convection, and from the storm's mechanical energy, these act effectively only after the development of the storm. The initial increase of temperature was probably due to the warming up of some large area by the direct heat of the sun, or the introduction of cold or chilled air currents of large extent.

c. The gyratory motion* "depends upon the effect of the earth's rotation, and may be, and generally is, sensibly independent of any initial motion of the atmosphere relatively to the earth's surface."

I. The effect of friction† of air against earth surface is, in a mathematical discussion of the motions of the air particles, quite apparent. Naturally so, when we remember that the "cyclone proper" is treated of as a broad thin "sink" of revolving air.

II. Tornado differs from a cyclone in

a. Extent of territory affected by it, the area being confined and compared with that of a cyclone proper, small.

b. In its "structure" (if we may use the term); being a column of air with base small in comparison with its altitude.

c. The gyratory motion depends on, or rather is determined less by, the earth's rotational effect, than by some local "strongly-acting" cause.

d. The frictional effects are less marked, as the surface exposed is so much smaller, though of course, the increased velocity augments the friction.

III. Tornado resembles cyclone proper in

a. It has its origin in the condition of unstable equilibrium of the atmosphere.

b. It has (according to Professor Ferrel)‡ "the same interchanging motion of atmosphere between central and exterior parts."

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* "Recent Advances in Meteorology," by Professor William Ferrel, Chapter V, page 287.

† *Effect of Friction.*—The linear gyratory velocity due to the earth's rotation, of any point of the earth's surface (as given by Ferrel, page 289) is 0 18 mile per hour at the parallel of 45°, at a distance of one mile from the centre. In the case of ordinary tornadoes, in which the distance is much less than a mile, the linear gyratory velocity per hour is small and may be neglected in comparison with the usual velocities in a tornado which may average 150 miles per hour. In the ordinary cyclone, however, the distance one mile becomes perhaps 250, and hence correspondingly greater frictional effects may be looked for.

‡ Chap. V, p. 287. "Recent Advances in Meteorology."

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To sum up, then; cyclones proper in structure are broad thin "sinks" of revolving air, with "a central calm, a strong oblique cyclonic inflow around the centre, a peri-cyclonic calm and faint exterior oblique outflow, all of which are best developed at the surface, and disappear or are reversed above";* the tornado, a secondary "*whirl*," in which at least four component motions may be noticed, an influx to the vortex from all parts, with a progressive motion to the northeast, and "always formed in the southeast quadrant of an area of low barometer."†

We have classified above hail-storms, water-spouts and thunder-squalls with the tornado, as a type of storm, and it is necessary at this point, therefore, to discuss briefly their relation to the tornado. As yet, we barely know more about these storms than the distinguishing features. They are all storms of comparatively small area and great intensity. They might be called "sub-cyclonic" or "secondary" storms brought about by the cyclone proper, and having a definite relation to the center of the larger storm, or as it is generally named, the storm-center. Of the particular "mechanism" and "construction" of each class, unfortunately we know yet but little, and the different causes at work we do not clearly comprehend. With regard to thunder-squalls we know that they occur in the southeast quadrants of "lows," follow the higher winds in their motions about the storm-center, rather than the surface winds, and in northern latitudes "advance to the east when they arise to the south of "a pronounced center of low pressure; to the west when they "appear to the north of these centers, though this last case is "infrequent."‡ "The winds are found to obey Buys-Ballot's law "*i. e.*, they flow obliquely to the right, down gradients;—and, "the clouds move in various directions."§ According to Von Be-"zold ‖ thunder-storms are especially frequent in the 'saddle' "of high pressure between two adjacent low pressure areas. ". . . Just in front of the storm-band the pressure suddenly "increases and the temperature suddenly falls; so that the "front margin of the storm separates a region of lower press-

*Wm. M. Davis: "Classification of Winds." AMERICAN METEOROLOGICAL JOURNAL, January, 1887, p. 516.

†J. P. Finley: "Character of Six Hundred Tornadoes."

‡AMERICAN METEOROLOGICAL JOURNAL, 1886, p. 498. W. M. Davis: "Foreign Studies of Thunder-storms."

§ Ibid.

‖ *Austrian Meteorological Journal*, August, 1883. Reference taken from Davis as above.

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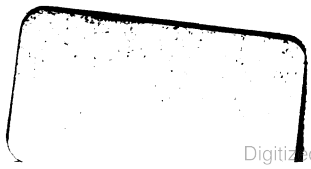

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TORNADOES.

SECOND PRIZE ESSAY.

BY

Alexander (George)

A. McADIE.

1890

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"pouring forth a torrent of rain. But there was a double rain-"bow projected on the clouds banking up over to the eastward, "and evidently rain was falling in the space between them and "the sun for some time after the last remains of the spout had "disappeared."

This account, like many others, makes us emphasize the following points:

First, all these storms, having a tornadic action, are creations of the moment, so to speak; and the conditions always found to prevail during their occurrence, if varying but slightly, may occur and re-occur, without the development of these storms.

Second, we may not always be able to discern the existence of these storms. There are undoubtedly many "whirls," "in-"cipient tornadoes," and "gyrating clouds" that pass harmlessly and unnoticed over our heads. If the quantity of water vapor in the air, at some given place, is not large, the condensation of it might not result in a cloud form that would excite our notice; or furthermore, the condensation might have taken place at such an altitude that the whirling motion of the air could not influence it sufficiently to bring the cloud thus formed down to the earth or sea surface.

Third, the barometer does not necessarily give warning of the proximity of these storms. This has been observed to be the case where a ship has sailed into a water-spout in process of formation, (and nothing in the way of a cloud or condensed vapor affording warning), with the barometer until the actual presence, almost of the storm, remaining unaffected.* At, or very close to the centre of the storms, the diminution of pressure is marked; and objects then experience not only the strong in-flowing, whirling and out-throwing forces, but also the destructive explosive forces, caused by the expansive action of the air confined within them.

So much has been said *with so little authority*, of electricity and the part it may play in connection with the development of the tornadic storm, that we hesitate here to make even a suggestion, though of a very different nature from those generally made. Our suggestion is that a future important use possibly awaits the *electrometer* (as used in the study of atmospheric electricity) as an instrument better adapted than any in present use, to give notice and warning of the proximity of violent

*Case of the British bark *Belle Stuart*, 160 miles from Cape Sable, Nov. 14, 1878. See Ferrel, p. 321.

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whirlings in the air. As we have seen, the barometer is too sluggish and the thermometric indications too much masked, to be serviceable. Besides it is questionable if the transmission of the pressure disturbance or the propagation of heat waves (meaning thereby, temperature changes) are very sensitive methods. We have found out from electrometer work, although yet but in its beginning, that by those peculiar properties appropriate to electricity, disturbances such as snowstorms, rainstorms, thunder-storms, give certain indications on electrometers far distant. Nothing has been done yet with these instruments in connection with the study of tornadoes; but without question, if these rapid whirlings, by friction, by inductive influences, or in ways not yet understood, bring about electrical effects (as it seems all too evident they do), we know enough to say that it is within our power to study these storms *at a distance;* and what is of the utmost importance, to detect those which would otherwise pass unheeded.

Fourth, as will be developed further on in this paper, perhaps the method which promises most in the way of obtaining knowledge bearing on the occurrence of tornadoes, is that of a careful study of cloud movement. Perhaps we shall detect many a tornado, and embryo tornado, in the "whirling" of cloud masses; and at least we shall have more light upon one of the principal conditions controlling tornado occurrence, viz.: "The state of "unstable equilibrium of the atmosphere." The matter of careful cloud study has not received the attention it merits, and it is time for a protest against directing our entire search for a better knowledge of meteorological phenomena to the borderland of their domain, rather than to the very home and seat of their occurrence.

From the studies that have been made of tornadoes, the following facts seem established beyond doubt:

First, two conditions must exist for the occurrence of a tornado,

a. A state of unstable equilibrium of the air;

b. A gyratory motion around some centre.

A third condition that naturally follows is that some local disturbance shall "cause the air to burst up at some point through "the strata above."*

Second, in northern latitudes tornadoes are always formed in the *southeast* quadrant of a cyclone proper,—as we have seen is

* Ferrel, page 325.

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the case with thunder-storms, hail-storms, and all those types of secondary storms. Naturally, from their relations to these larger disturbances, we should expect to find that the general progressive motion of these storms is *northeasterly.*

Third, tornadoes are not necessarily visible.

Fourth, their general distribution (statistics deal only however with those in which the tornadic action has extended downward to the earth-surface) depends on the more general movements of the atmosphere, as determined by geographical conditions.

The following more specific facts have been obtained from the studies of the Signal Office, and are given by Finley* in his "Character of Six Hundred Tornadoes":

a. "The places and times most favorable to the development "of unstable equilibrium and a gyratory motion of the atmos- "phere, are those in which tornadoes are most likely to occur." . . . "Where warm, moist air flows underneath colder and "dryer upper strata coming from another direction. Such "regions are found particularly in the Mississippi, Missouri, "and Ohio valleys, and in Alabama, Georgia, and the Car- "olinas."

b. "The month of greatest frequency is May."

c. "Shortest time occupied by the tornado cloud in passing a "given point varies from an instant (?) to about twenty minutes. "The average time is seventy-four seconds";

d. "Width of path of destruction from ten feet to 10,560 feet, "with an average of 1,369 feet."

e. "Length of tornado track (on ground (?)) from 300 yards "to 200 miles, with an average of 24.79 miles."

f. "Velocity of progression of tornado cloud, from seven to 100 "miles per hour, with an average of 44.11 miles per hour."

g. "Vortex wind velocities vary from 100 to 500 miles per "hour as deduced from actual measurement."

h. "The concomitants of a tornado are oppressive condition "of air; rapid decrease of temperature with increase of alti- "tude; a decided gradient of temperature across the line of "progressive movement; a characteristic funnel-shaped cloud "which on reaching the earth has four motions, whirling mo- "tion from right to left, progressive motion from SW to NE a "curvilinear motion and an oscillatory motion."

* See also Paper read before National Geographic Society, Washington, Nov. 16, 1888, reprint *Science*, Feb. 1, 1889.

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We come now to the second division of our paper, concerning the *possibility* and *practicability* of *predicting tornadoes.* We are not yet able to prevent the occurrence of tornadoes. The tornado cloud itself disappears, most probably, not when the conditions in the "whirl" no longer cause rapid condensation, but when, indeed, the conditions favorable to re-vaporization begin to strongly assert themselves. Could we copy nature, and provide those very oppositions, which she provides, we might, if not destroy, at least remove the tornadic action to regions where its effects would endanger neither life nor property. Coldness and dryness of the air are undoubtedly unfavorable to the growth of tornadic action, as per contra, warmth and moisture favor it. It is said, that tornadoes are unknown west of the 105th meridian, because of the dryness of the air. It may be pointed out here, too, that tornadic action originates not at the surface of the earth, but in the upper regions of the air. So also, in the disappearance of a tornado, it is in the upper regions that the tornadic action finally dies out. The lower part of the characteristic cloud is always the part which disappears first. But as we may not yet prevent, nor successfully interpose barriers between ourselves and the storm, let us turn our attention to the most profitable means of obtaining fore-warning of its occurrence. The Signal Office began on July 1st, 1886, the preparation of a special chart, having for its purpose, the indication of where a likelihood of tornado occurrence might be. This chart, after two years' trial, for reasons not made public, was discontinued, a general weather map being considered as serving equally well. State of weather, as regards cloudiness, wind direction, temperature and the depression of the dew-point below the temperature of the air, were entered on this map. *The regions of northerly and southerly* winds were distinguished from each other by heavy carbon lines. There is no criticism to be made upon this chart, so far as it goes; but it certainly suggests to an inquiring mind, an indefiniteness and incompleteness concerning those very features, on which the occurrence of tornadoes depend. In the Indications work of the Signal Office, for years, only the barest kind of attention has been given to the study of some of the most important of meteorological factors. The tendency to rapid generalization and hurry in the work of that Division bars, from careful consideration, matters of detail, it is true, but still of great importance in the making of predictions. The conditions are

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often so suggestive that it seems almost certain that their careful study could not fail to improve the percentage of verifications.

Unless valid reasons can be given, the tornado chart, or a chart that could be equally serviceable for thunder-storms, hail-storms, etc., should be reissued. And this chart should show, first, the border ground where currents from cold dry regions are brought into opposition with those from warmer latitudes. This was the design of the carbon line separating north and south winds, on the original map, as suggested, we believe, by Lieut. Finley. The second consideration, that of temperature, presents difficulty in charting, at the start, because we have not the means of ascertaining what are fairly representative temperatures, not alone of air strata but even of limited areas near the surface of the earth. We need in meteorology, above all things, *integrating* thermometers; some system of thermometry that shall sum up fairly, and represent justly, the heat effects over given areas. The new tornado chart should therefore indicate regions in which an unusual warning up of the lower strata seems to be in progress, particularly if this heating effect seems to be confined in extent to low air strata, while approximate higher strata seem to remain comparatively unwarmed. The use of the dew-point depression might perhaps be better served, by giving the absolute humidity of the air. As with thermometry, the value of integrating instruments is obvious, and the employment of isolated observations productive of but uncertain results. The features of wind direction and velocity as regards the proposed chart are most important. For, from the wind direction, and the direction of cloud movement (a matter singularly unappreciated by some professional meteorologists) we can obtain best, and independently of barometric indications, a knowledge of the gyratory motion of the atmosphere, relative to any centre; and the "fixing" or locating of this centre. The charts in the Indications Room of the Signal Office take passing notice of the directions of cloud movement, but no use is made of these directions as a means of locating centres of gyratory motion of the air. It is here suggested that this chart for use in tornado prediction show for all stations reporting, in addition to the features above named, the velocity and direction of the surface winds *and also the directions and apparent velocities of cloud movement.* We can not over-emphasize the importance of taking recognition of the *upper*, as well as the lower strata of

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the air. In the actual charting the surface wind might be represented by an arrow, flying with the direction *below* the station, and the cloud direction by an arrow *above* the station. Where two or more kinds of clouds are reported, two or more arrows might fly above the station, the arrow representing the uppermost clouds having the uppermost position; thus

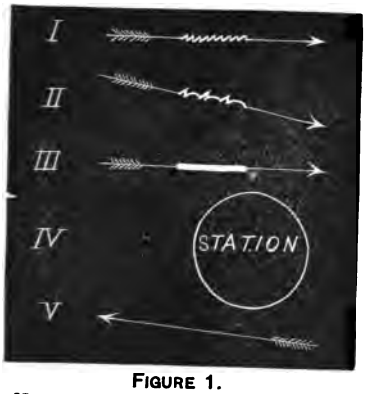

FIGURE 1.

cirrus clouds from west,
cir-cu. clouds from northwest,
stratus clouds from east,
surface wind from southeast.

Some scheme must be employed (as for example, prolonging the arrow HEADS of all *lower* directions, and the arrow TAILS of all *upper* directions, to the supposed (partially indicated) centre of gyratory motion) whereby these motions of air strata may be made to indicate, not alone the *general centre* of gyratory motion, but if sufficient observations are given, the TENDENCY to the formation of any *secondary* centre of gyratory motion.

The following diagram is offered. in illustration of the suggestion (see chapter in Ferrel on "Relations between Upper and Lower Strata of Air"). Full arrows represent lower clouds, and dotted arrows upper.

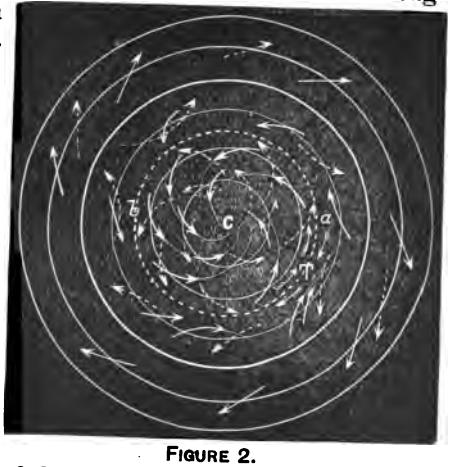

FIGURE 2.

We should strive in every way to obtain a knowledge that will enable us to locate definitely, not only the *general centres* of gyratory motion, but also the various *secondary centres* of whirling. We hear sometimes, of failures in prediction accounted for as "unaccountable." "Everything" we are told "seems to indicate that 'thus and so' would happen—and the predictions were made in accordance with known laws!" It is

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these very irregularities, these unaccountable (!) wind directions, these inexplicable (until subsequent explanations are attempted) delays in the progressive movements of "storm-centres," these unlooked for and unpredicted cold and warm "waves" that contain the very secrets of successful prediction. As it was from the perturbations of the planet Uranus that Adams argued the existence of the planet Neptune, and Leverrier directed the Berlin astronomers where to look to find it, so, we believe, it will be from a most careful and detailed study of these secondary whirlings in our atmosphere, that the seeming irregularities and uncertainties of the primary whirlings will be made known; and the prediction not alone of storms of marked intensity as *e. g.* tornadoes, thunder-storms, etc., be made possible; but the ordinary predictions of general weather conditions be made eminently successful.

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